

Thermal neutron-induced fission cross sections of Cm isotopes

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SCK·CEN, ANS-RNM

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Katholieke Universiteit Leuven
Université Libre de Bruxelles
Universiteit Gent
SCK•CEN



GANIL, Caen
IKP, Köln
GSI, Darmstadt
CSNSM, Orsay

(n,f) reactions on MA

Applications

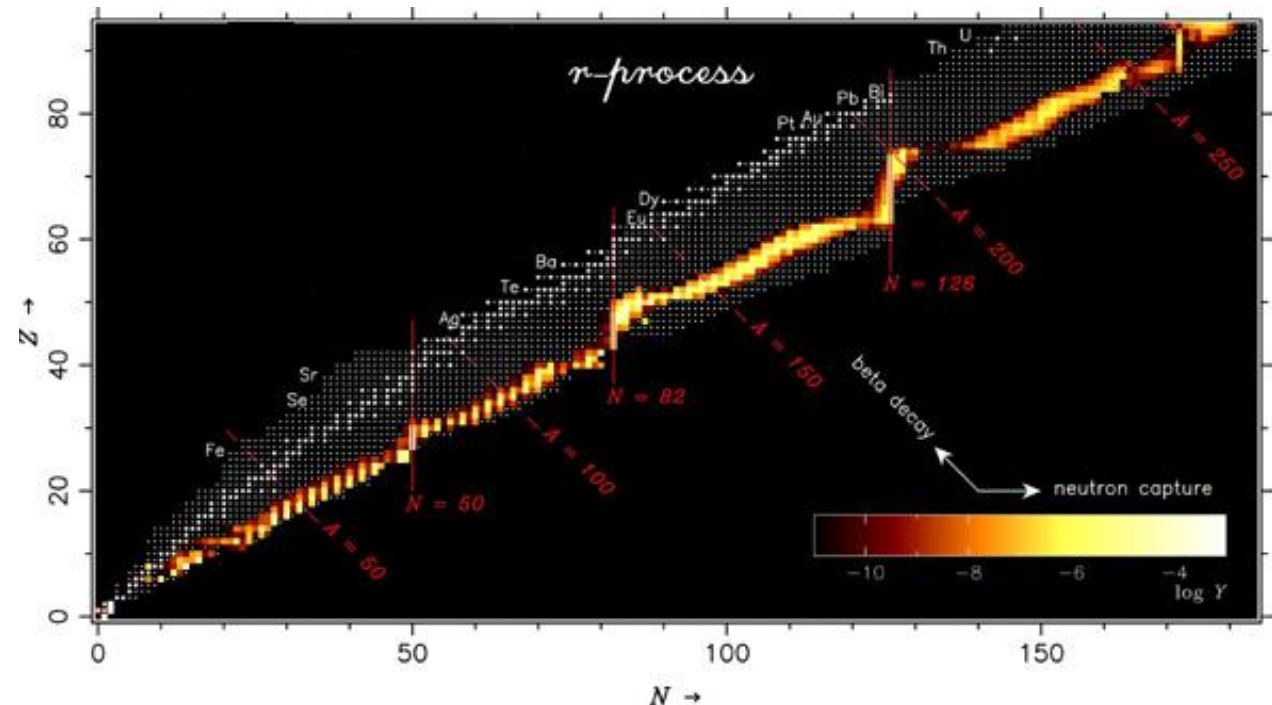
- Nuclear reactors (SCK·CEN)
- Nuclear astrophysics (Univ. partners)

Cross section measurements

- Thermal region (SCK·CEN)
- Resonance region ($E_n < 10\text{keV}$)(IRMM)
- Accurate determination of Westcott factors

Nuclear astrophysics application

r-process nucleo- synthesis

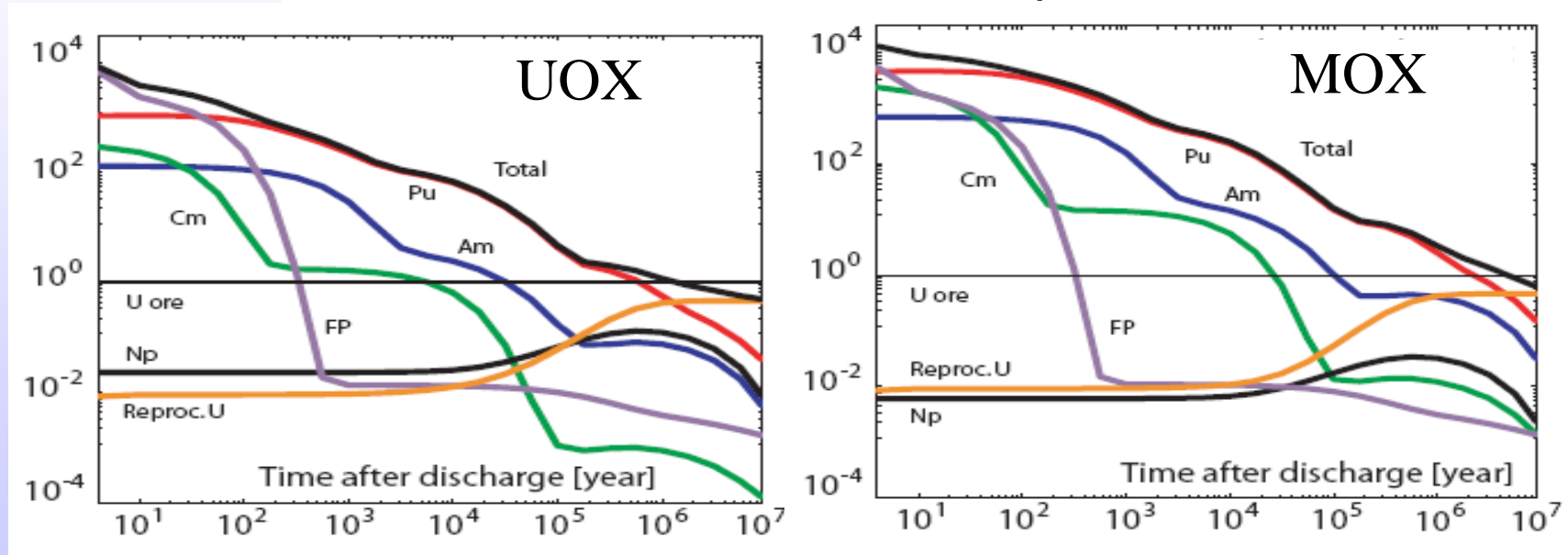


- Responsible for the yields of TU elements
- Terminated by fission

Nuclear reactors application

- Cm nuclei – present in the HLRW

Relative radiotoxic inventory



Nuclear reactors application

Basic parameters for most important actinides from LWR

Nucl	Half-life [year]	UOX 41.2 GWd/t	UOX 50 GWd/t	MOX 43 GWd/t	e_{50}^{ing} [10^{-8} Sv/Bq]	
		[kg/tHM]	[kg/tHM]	[kg/tHM]	<1 year	adult
^{235}U	$7.04 \cdot 10^8$	6.6	6.5	N/A	35	4.7
^{238}U	$4.47 \cdot 10^9$	938	929	N/A	34	4.5
^{237}Np	$2.14 \cdot 10^6$	0.55	0.71	0.16	200	11
^{238}Pu	87.7	0.27	0.42	2.5	400	23
^{239}Pu	24100	5.9	6.2	21.5	420	25
^{240}Pu	6563	2.6	2.9	17.9	420	25
^{241}Pu	14.4	1.4	1.5	8.3	5.6	0.48
^{242}Pu	$3.73 \cdot 10^5$	0.74	0.95	7.2	400	24
^{241}Am	432.1	0.34	0.38	3.0	370	20
^{243}Am	7370	0.19	0.28	1.9	360	20
^{243}Cm	29.1	$<10^{-3}$	$<10^{-3}$	0.014	320	15
^{244}Cm	18.1	0.056	0.098	0.80	290	12
^{245}Cm	8500	0.004	0.007	0.10	370	21
^{246}Cm	4730	$<10^{-3}$	0.002	0.006	370	21

(n,f) reactions on MA

$^{243,245,247}\text{Cm}$ (n,f) – measurements @ BR1 facility

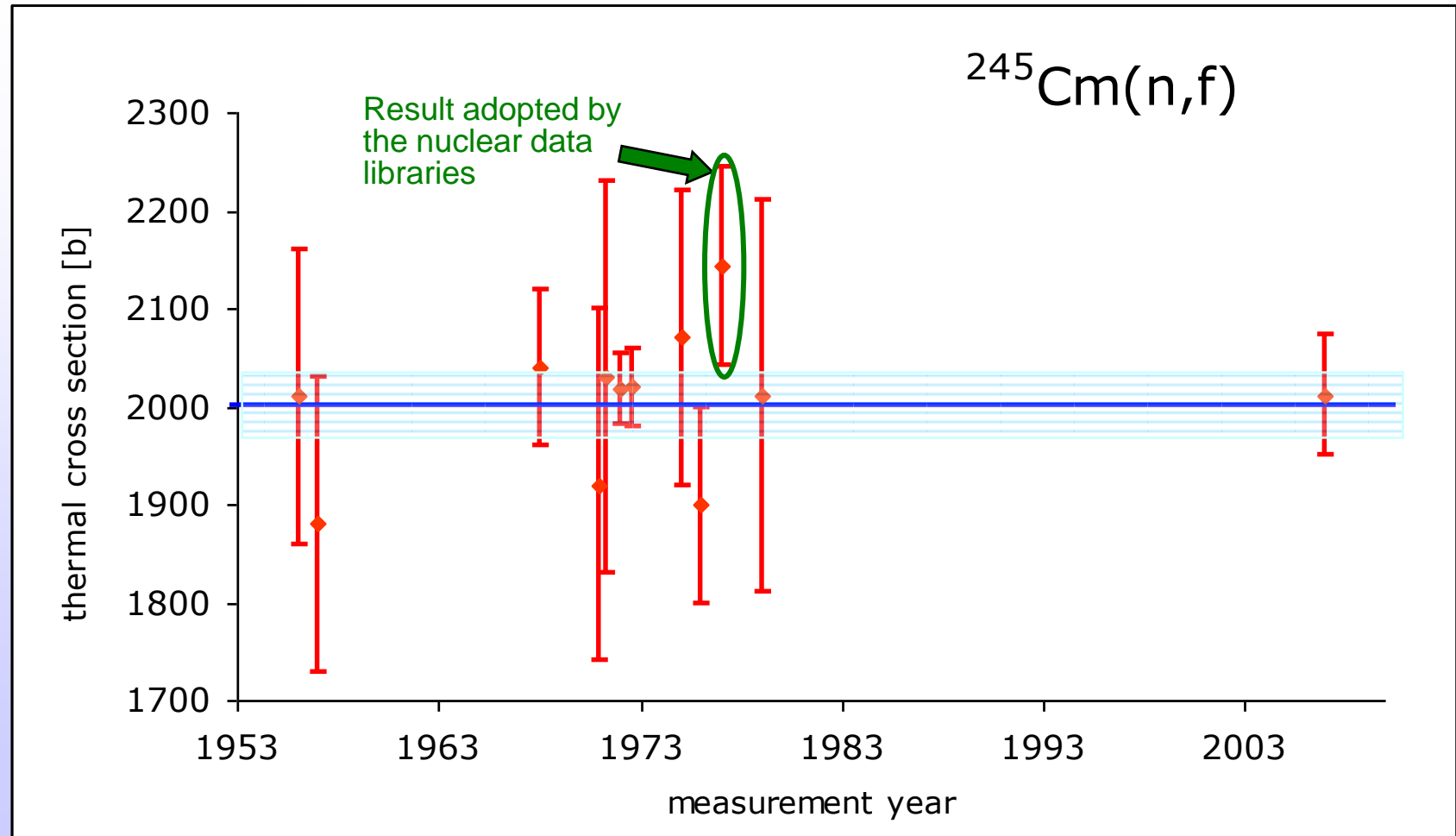
- Choice based on available sample characteristics, cross section and Φ_n

Nuclear data libraries

- Adopted cross sections σ_0^f

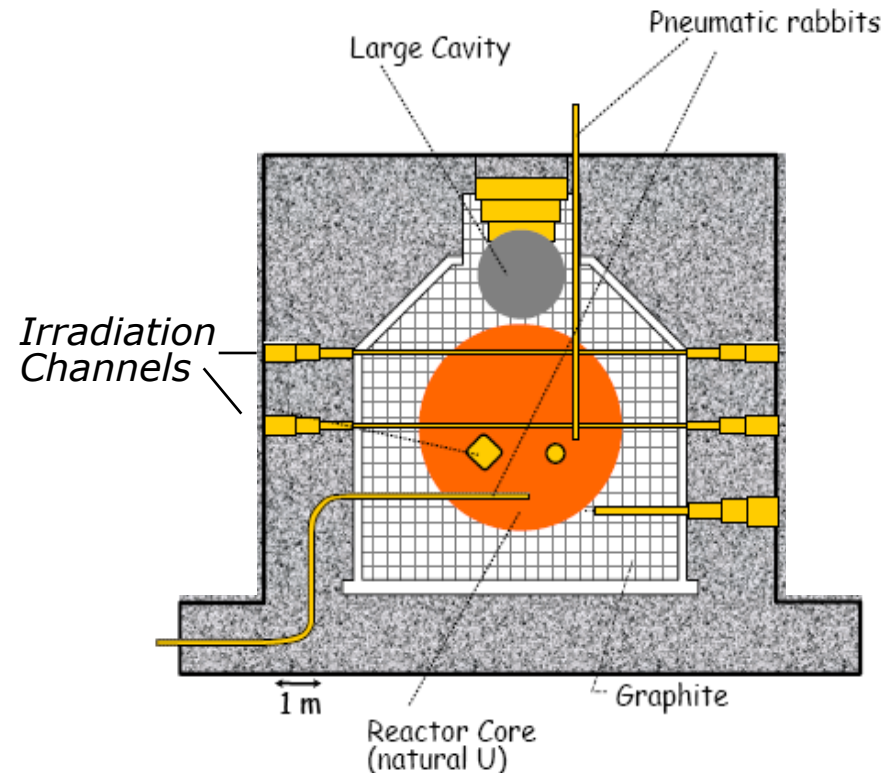
Nucleus	ENDF B-VII	JEFF 3.1	JENDL 3.3
^{243}Cm	613.3 b	617.4 b	613.3 b
^{245}Cm	2142.4 b	2142.4 b	2142.4 b
^{247}Cm	111.3 b	81.8 b	111.3 b

Available nuclear data



SCK·CEN - BR1 facility

- Graphite moderated, air cooled reactor
- Well thermalized neutron-beams at the exit of the irradiation channels
- $v_n = 2200$ m/s
- $\Phi_{th} \sim 6 \times 10^5$ n/s/cm² at sample position (700 kW)
- Several irradiation channels
- Multiple experiments running simultaneously



Measurements of interest

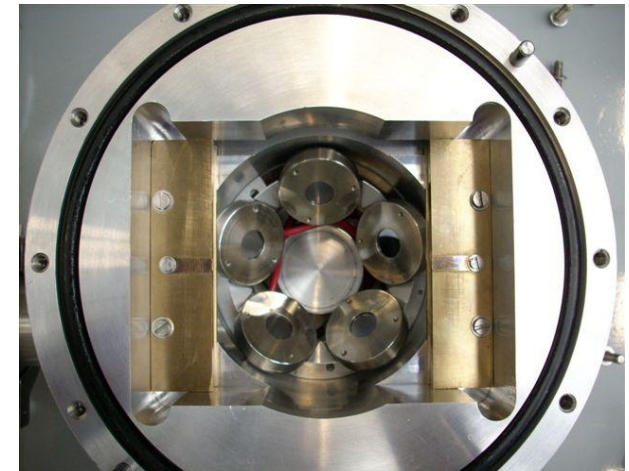
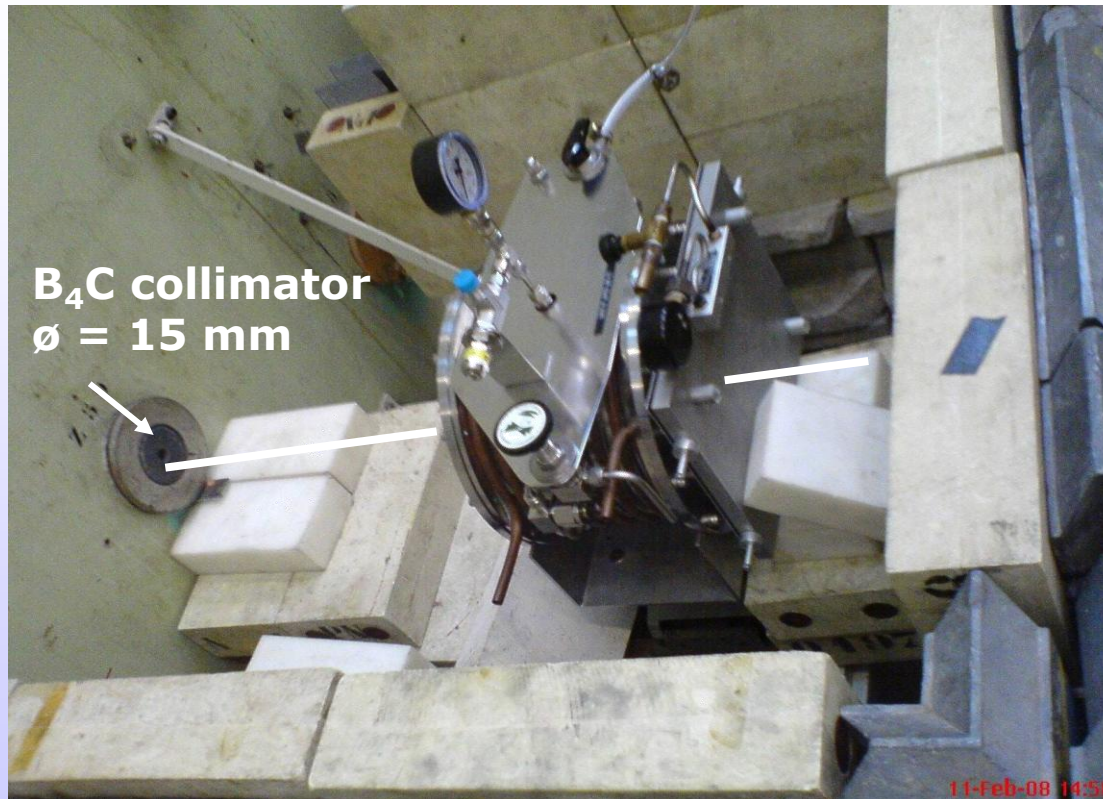
- Estimated counting rates (CR) for a 2π geometry:

<i>Sample</i>	Mass [μg]	Purity [%]	Activity [MBq]	CR α [α/s]	CR SF [SF/s]	CR (n,f) [cts/s]
^{243}Cm	2	98.35	3.16	1.58×10^6	0.1	1.5
^{245}Cm	141	98.48	4.7	2.35×10^6	7.3	387
^{247}Cm	1	72.51	1	0.5×10^6	55.3	2.8

- Issue: background generated by SF and the pileup of several " α -signals"

Experimental setup

- Surface Barrier Detectors (SBD)



- Fast response
- Good energy resolution

- Installed @ BR1, Z59 channel / B-side

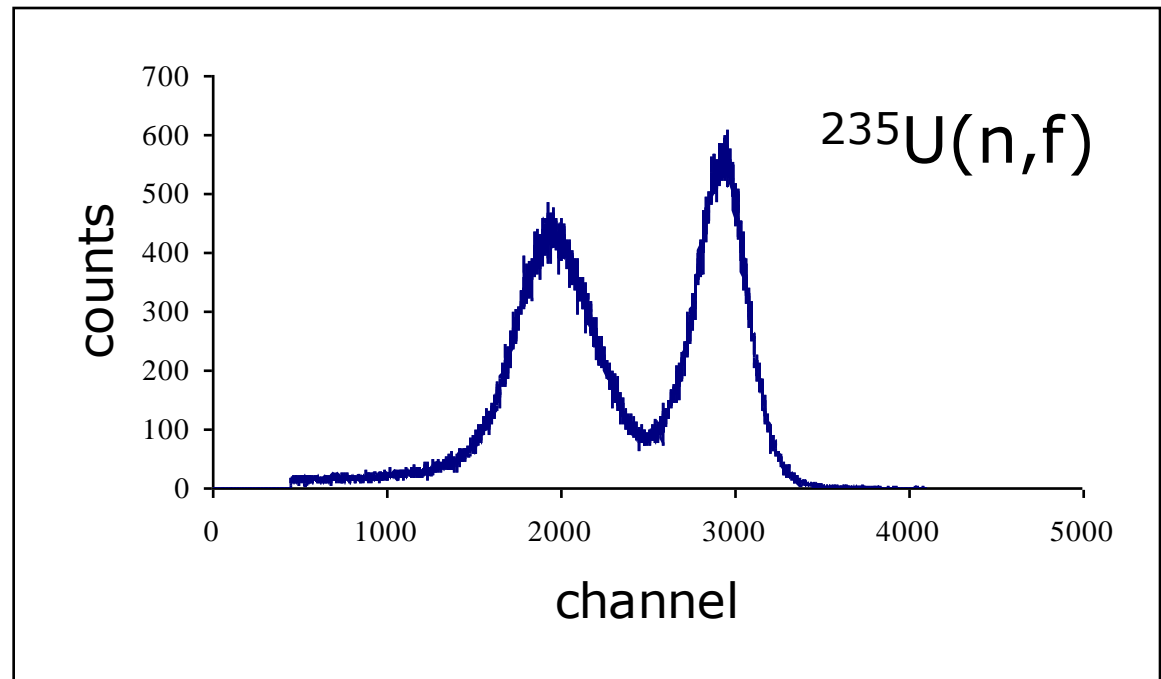
Beam flux measurement

- $^{235}\text{U}(n,f)$ – Φ and ε measurement

- well characterized sample
- well known σ
- measurement with & without n_{th} - filter



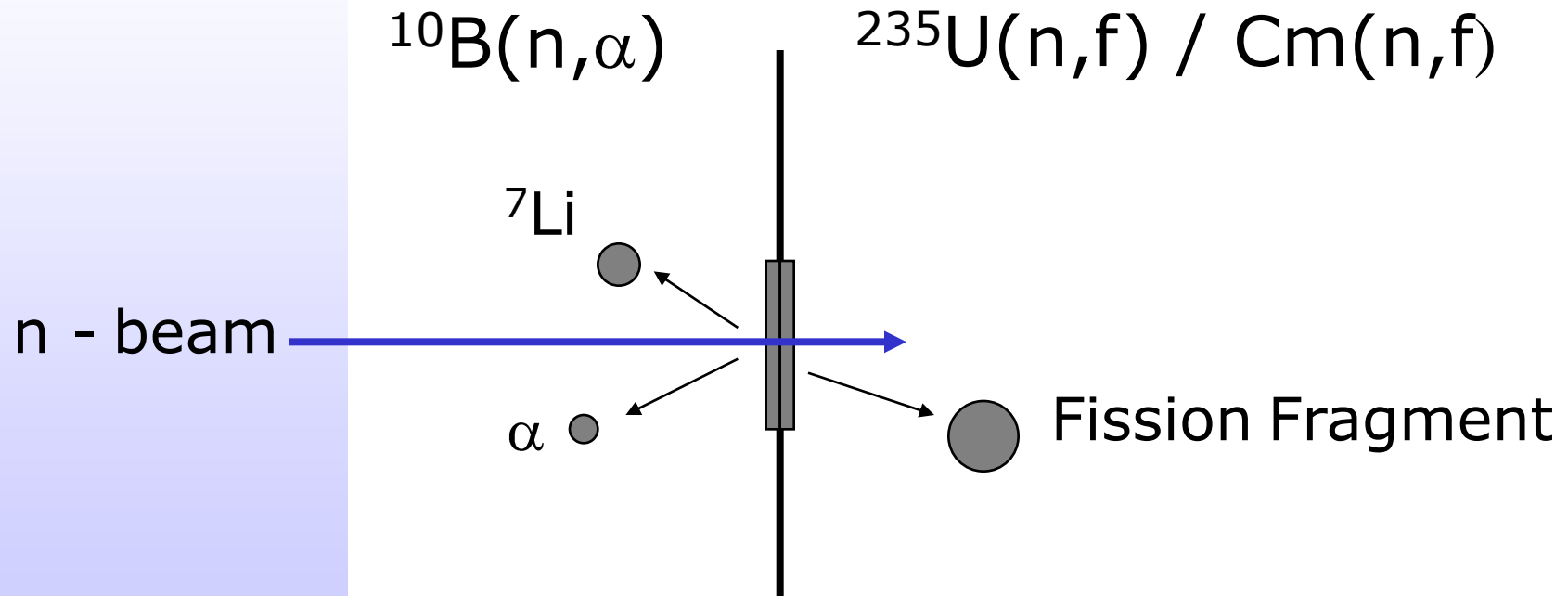
$$\Phi_{\text{th}} / \Phi_{\text{epi}}$$



$$\Phi_{\text{th}} \sim 6 \times 10^5 \text{ n/s/cm}^2$$

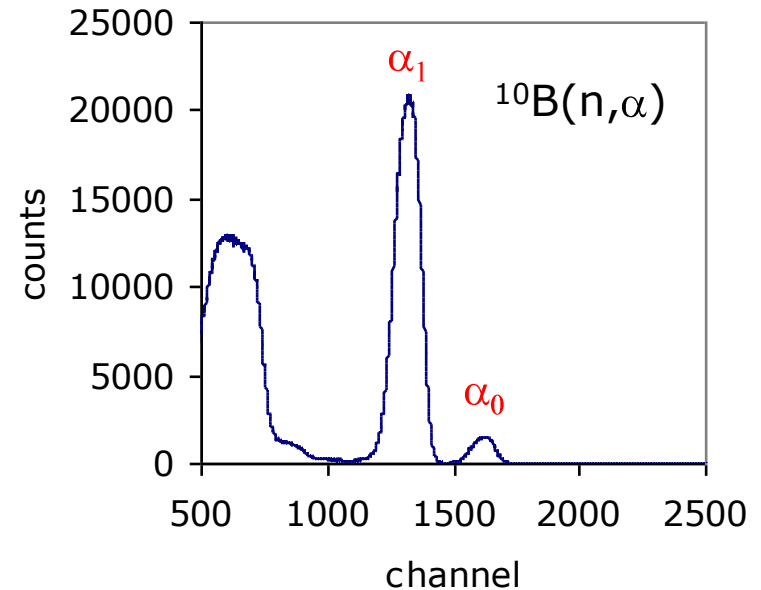
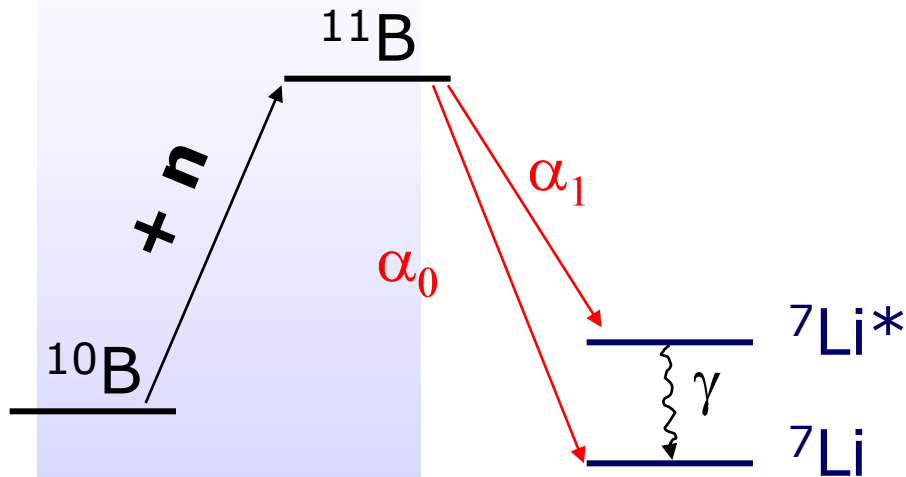
Back-to-back measurements

- ^{10}B sample-used for monitoring



Monitoring measurement: $^{10}\text{B}(n,\alpha)^7\text{Li}$

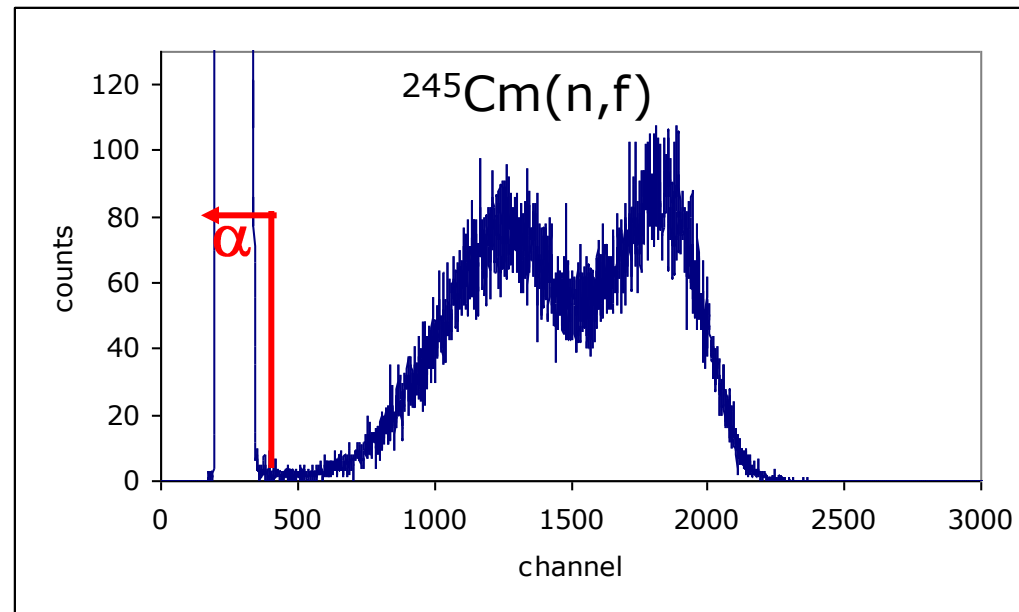
- Monitoring the flux and environment conditions



-high thermal cross section $\sigma_{th} = 3\,842\text{ b}$
 \Rightarrow Fast feed-back of perturbed experimental conditions
 - low background

$^{245}\text{Cm}(n,f)$ measurement

- Good separation of α - signals from fission fragments



- Counting rate: ~ 5.4 FF/s

$^{245}\text{Cm}(n,f)$ cross section determination

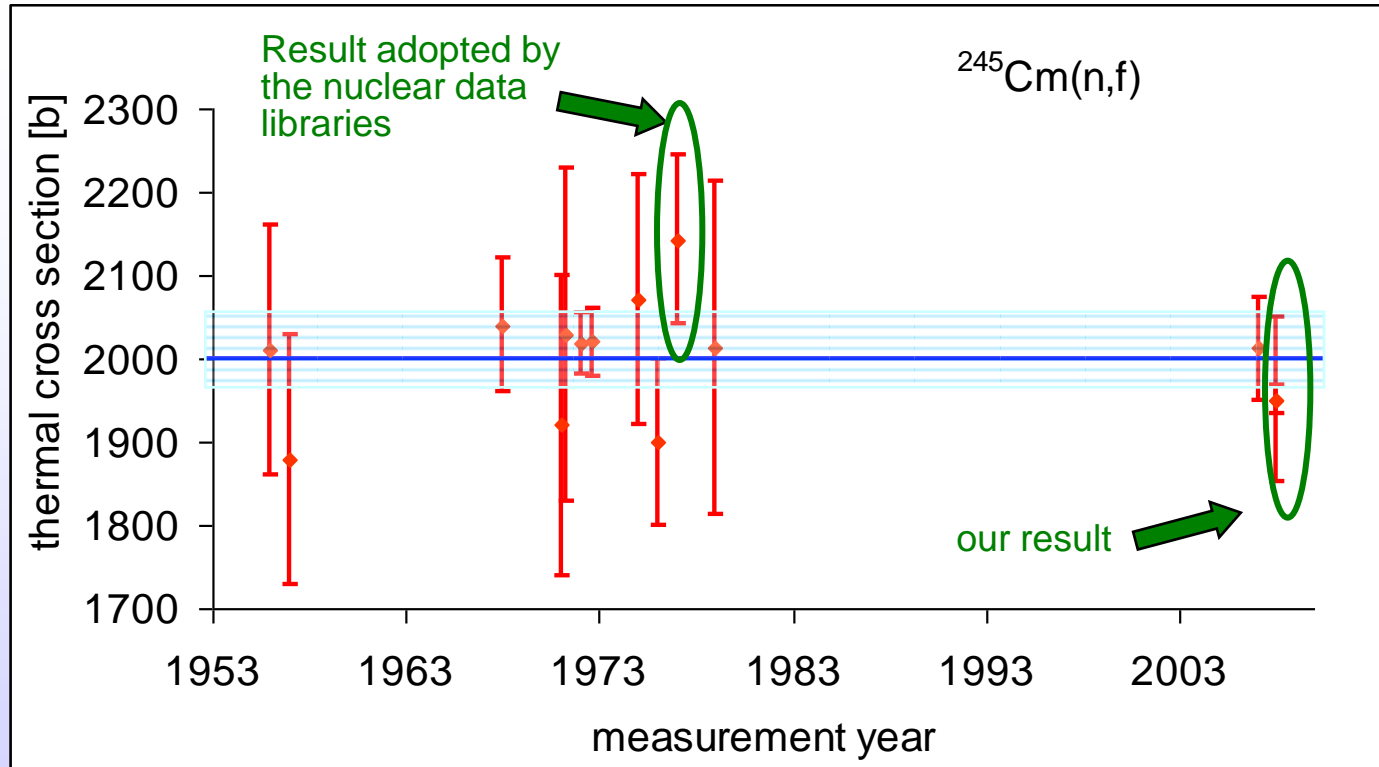
- Corrections:
 - 1.6% contributions SF
 - 2.6% contributions epithermal beam
 - <1% difference in beam-flux compared to ^{235}U measurement
 - Temperature dependence

Westcott factors: $g(^{235}\text{U})=(0.9771\pm0.0008)$
 $g(^{245}\text{Cm})=(0.954\pm0.033)$

- Result (preliminary):

$$\sigma_0^f(^{245}\text{Cm})=(1951 \pm 18^{\text{stat}} \pm 81^{\text{syst}}) \text{ b}$$

Preliminary result



- Our result: $\sigma_0^f(^{245}\text{Cm}) = (1951 \pm 18^{\text{stat}} \pm 81^{\text{syst}}) \text{ b}$

Conclusion

- New experimental program set up at the BR1 reactor (SCK·CEN)
 - 1st objective: measurement of $^{243,245,247}\text{Cm}(n,f)$ c.s.
- Experiments performed in collaboration with the University of Ghent and IRMM
- $^{245}\text{Cm}(n,f)$ measurement – finished
 - Results in agreement with previous studies
 - High accuracy
- $^{243,247}\text{Cm}(n,f)$ measurements – on going

Acknowledgement

- Experimental work performed with the help of collaborators from

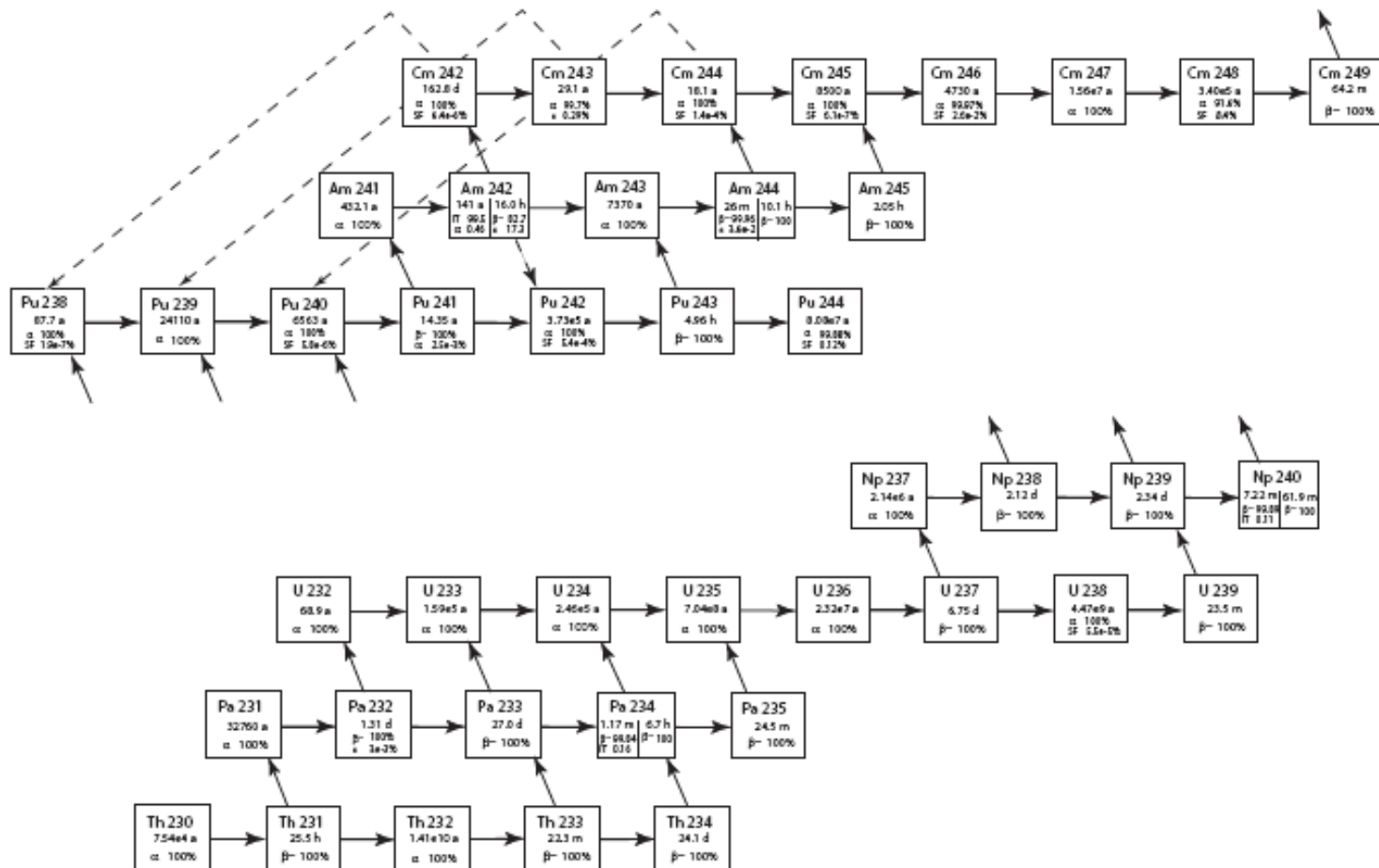
University of Ghent



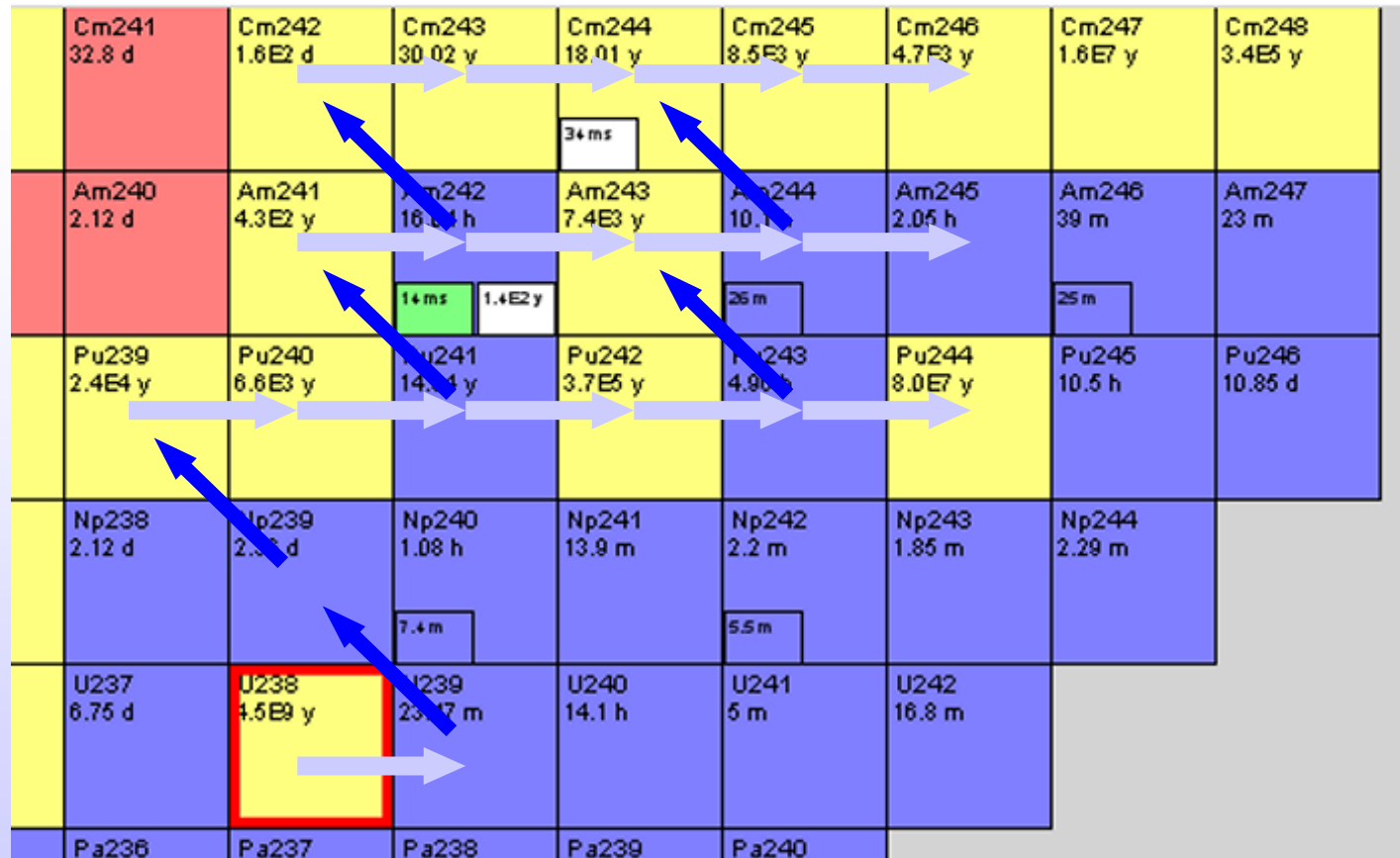
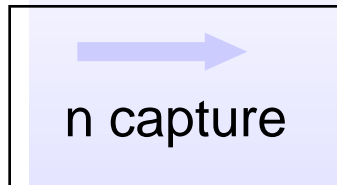
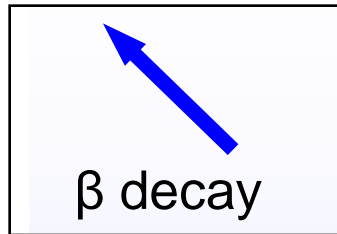
Backup slides

Build-up of Cm nuclides in a nuclear reactor

Transmutation paths for actinides



Build-up following U-238 n-capture



arrows indicate principle pathways; branching ratios and isotope proportions depend on n capture cross sections and half-lives

Comparison of Existing Data

$\sigma(25.3 \text{ meV})$

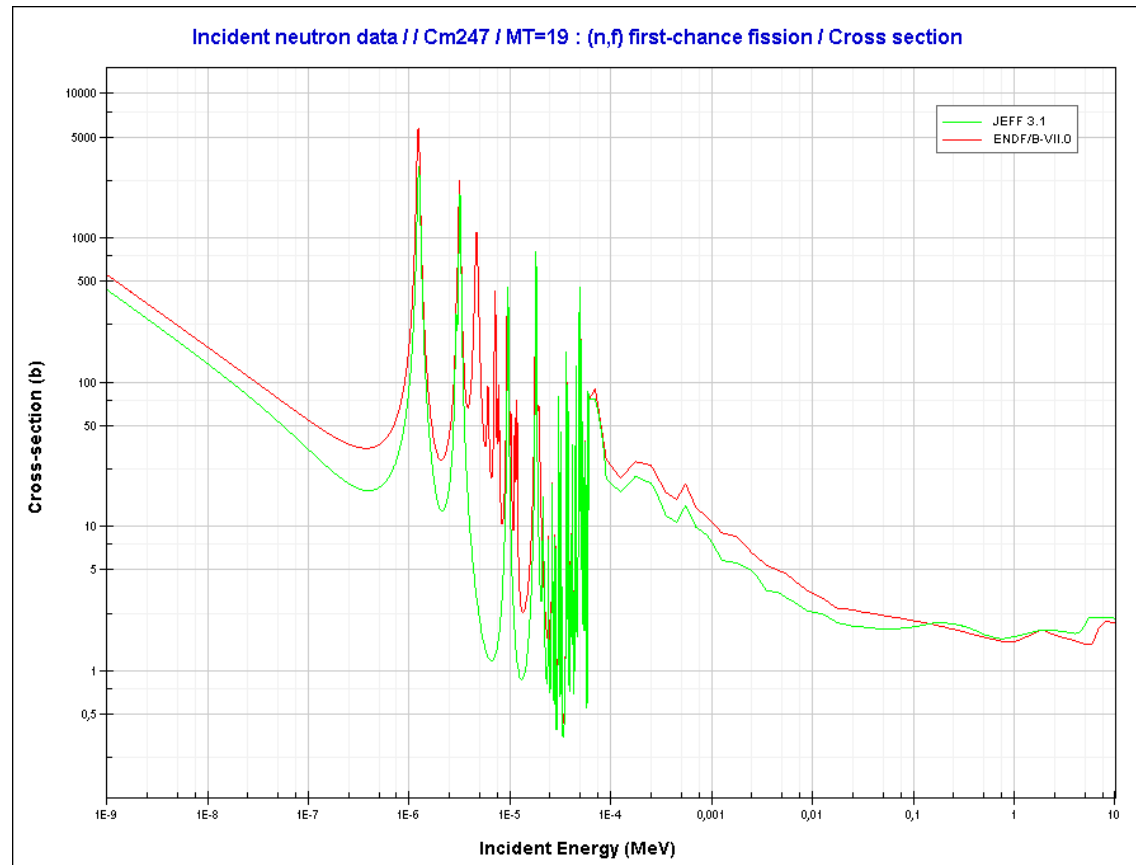
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(ENDF/B-VII.0)

111.35 b

(JEF 2.2)

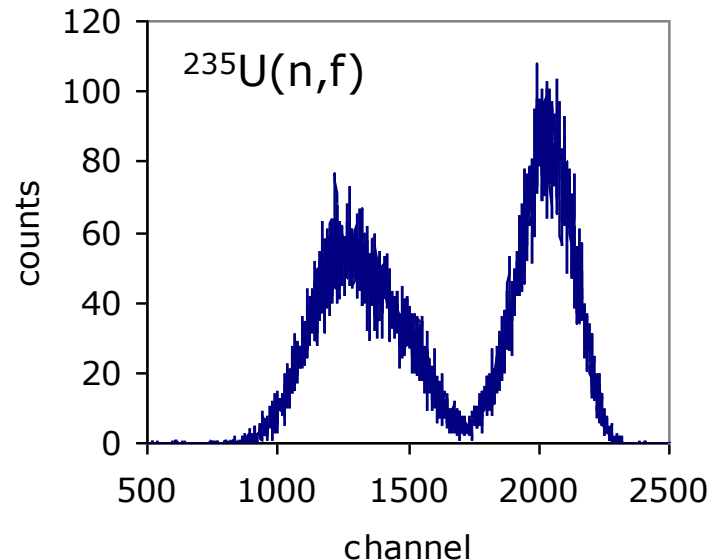
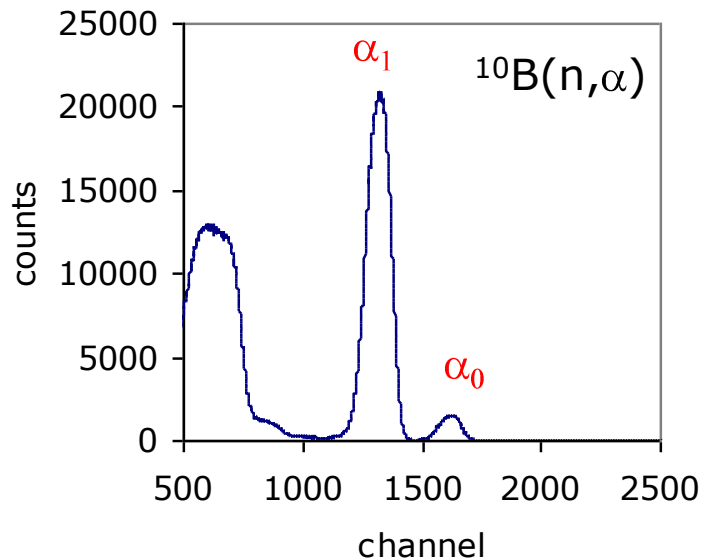
81.83 b



^{247}Cm (n,f) first-chance fission

Test measurements with SBD

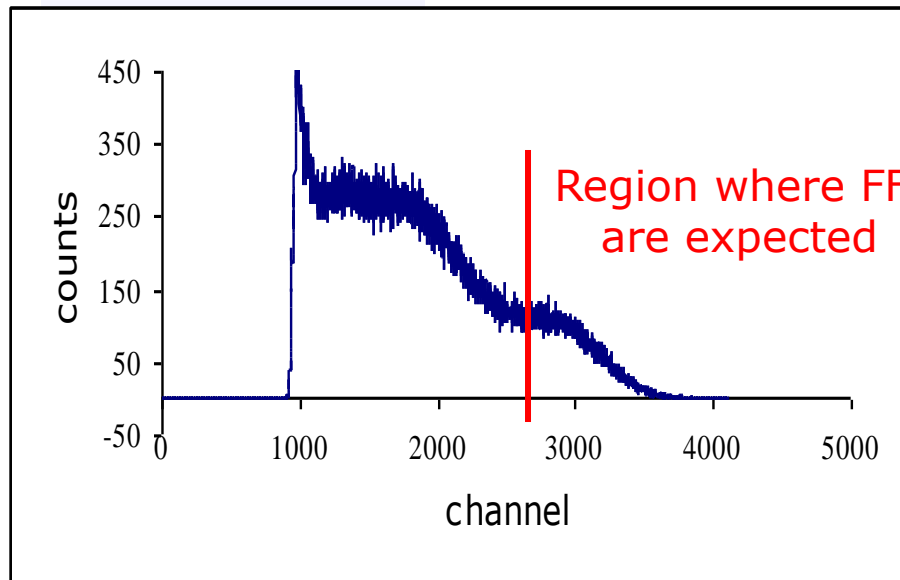
- $^{10}\text{B}(n,\alpha)$ and $^{235}\text{U}(n,f)$ measurements



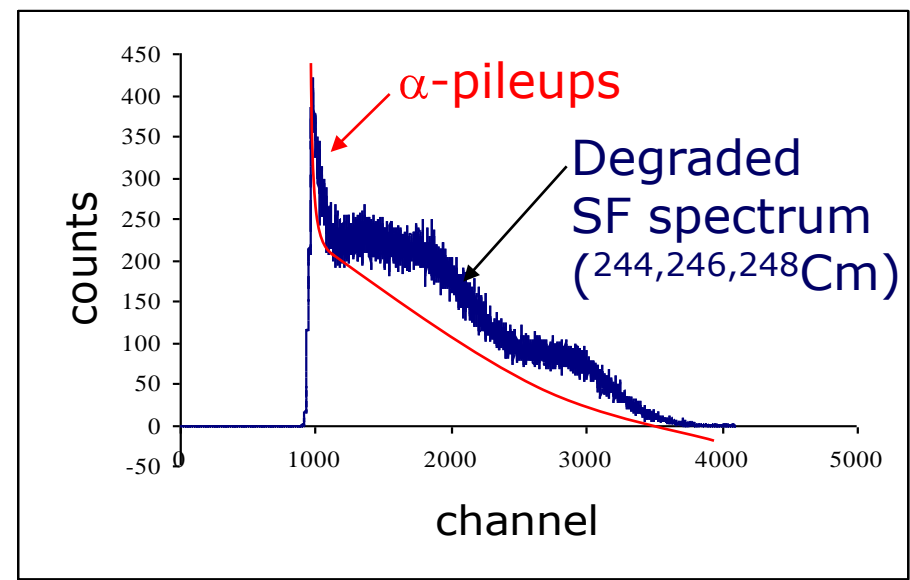
- good energy resolution
- efficiency: $\sim 1.4\%$ for (n,f) detection

Measurement of $^{247}\text{Cm}(n,f)$

- ^{247}Cm sample: Activity = 1 MBq - first test of handling high counting rates



BR1@700kW



BR1 - OFF